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DESIGN AND IMPLEMENTATION OF ZETA MICRO-INVERTER FOR SOLAR PV APPLICATION

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ABSTRACT

Microinverter is attached on each photovoltaic (PV) panel, i.e., Microinverter is improving due to increased energy harvest from the solar panel. This paper proposes a design and implementation of a single stage ZETA Microinverter for solar PV applications. This method is based on ZETA converter, with high frequency (HF) transformer isolation and a single low side switch on the primary side of transformer. The proposed inverter is its ability to work in Continuous Conduction Mode (CCM) over a wide load range, which results in reduced current stress, components rating and high efficiency. All the secondary switches operate at line frequency, thus reducing switching losses. In order to maximize the output of a PV system, the maximum power point (MPP) is used. A 60 W Microinverter was designed, developed, and tested.

KEYWORDS: ZETA-Microinverter, Photovoltaic (PV), AC Module, Continuous Conduction Mode (CCM), MPPT(P&O)

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Original Article

I. INTRODUCTION

A series connected PV panels with a single large inverter (string inverter) can be used to feed power into the grid with a common Maximum Power Point Tracking (MPPT). However, this is an inefficient way of harvesting energy because individual MPPT of solar panels is not done. A panel mismatch, shading or formation of debris will reduce the energy harvest significantly. To solve the above-mentioned problem, the concept of Micro inverter is picking up. Micro inverters are attached at the back of a PV panel and directly generate ac with MPPT. Improving the efficiency, reducing number of power conversion stages, and scalability are major design considerations.

Basic DC-DC converters such as Buck, Boost and Buck-Boost were investigated to operate under basic feedback control where the controller gains are determined from the pole placement approach formulated in the Linear Matrix Inequalities (LMIs) framework. This control is able to improve DC-DC converters performance with regard to the step response and steady-state error. Controllers such as PID, also come as good choice, being applied in controlling inverters.

The single-stage Micro inverters, fly back converter with a line frequency inverter (LFI) is the most commonly reported topology as there is only one main switch on the primary. Most of the fly back inverters reported in literature operate under discontinuous conduction mode (DCM). DCM mode of operation leads to higher inverter losses, current stress and component rating compared to CCM operation. This is due to the control complexity caused by the right half plan (RHP) zero when fly back converter is operated in CCM. To address the

problems in fly back inverter and to achieve CCM operation with a moving RHP zero, Li & Oruganti proposed control strategies and demonstrated significant efficiency improvement.

Modelling of ZETA dc/dc converter and parameter selection to eliminate RHP zero was earlier reported. It is concluded that ZETA converter can achieve higher bandwidth, and good closed loop stability. A DCM mode ZETA converter based inverter was earlier reported. The inverter power rating was limited to 80W. Low switching frequency (20 kHz) operation resulted into a larger filter and transformer.

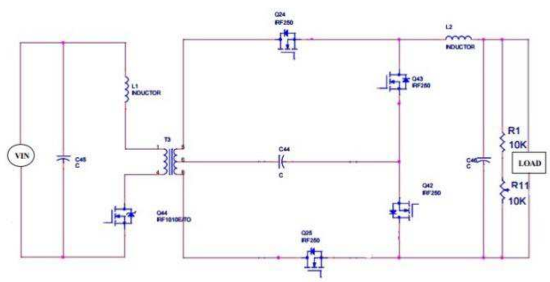

Figure 1: ZETA Microinverter

In this paper, a single stage CCM ZETA Micro inverter is proposed, with a single primary switch and four secondary switches.

II. PROPOSED TOPOLOGY AND DETAILED ANALYSIS OF CCM ZETA MICROINVERTER

This Section the steady-state operation of proposed Micro inverter. To simplify analysis, the following assumptions are made:

- All semiconductor devices are ideal and lossless
- Input voltage ripple is negligible.

Operation of ZETA Micro inverter is described for the +ve half cycle of load current at switching frequency. The main switch S_m is fixed at High Frequency with a variable duty cycle to generate rectified AC output and Secondary Switches S_1 - S_4 are operated. On the secondary side, during +ve half cycle of load current switches S_1, S_3 are gated to conduct and during –ve half cycle of load current, switches S_2, S_4 are conduct by giving gate signal.

CCM Mode of Operation

Interval 1 ($t_{c0} < t < t_{c1}$)

At $t = t_{c0}$, the main switch S_m is tuned-on and secondary switches S_1, S_3 are conducting throughout the positive half cycle. This interval is common to both DCM and CCM but prior to this interval the voltage across the primary of the transformer is non-zero, thus the current in the primary starts from a minimum value. In this interval input voltage, V_{in} is applied across the magnetizing inductance L_m of the transformer. Diode D_{s2} is reverse biased, thus the secondary switch current i_{s2}= 0 in this interval. Mathematical equations for the various current are

$$(\ ) = \quad (\ _0) + [\text{—} + \frac{2}{0}](\ - \ _0) \tag{1}$$

$$(\ ) = \quad (\ _0) + [\text{—}](\ - \ _0) \tag{2}$$

$$(\ ) = [\frac{(\ )-\ (\ )}{}] = \ _0(\ ) = \ (\ ) \quad (3)$$

At the end of this interval, flying capacitor is discharged to V_{cf_min}, currents I_p, $I_{Lm}$and I_{Lo} reach their peak values which can be represented by I_{p_peak}, $I_{Lm_peak}$and I_{Lo_peak}, respectively and are given by

$$(\ _1) = \ = \ (\ _0) + [\frac{}{}](\ ) \quad (4)$$

$$(\ _1) = \ = \frac{-}{} \quad (5)$$

This interval with duration DT_s ends when the main switch S_m is tuned-off.

Interval 2 ($t_{c1} < t < t_{c2}$)

At $t = t_{c1}$ the main switch S_m is turned-off and secondary side diode D_{s2}goes into conduction. At the start of this interval, the diode current is equal to peak primary current I_{p_peak} referred to secondary. Flying capacitor voltage V_{Cf} appears across the magnetizing inductance, but the average voltage across the output capacitor and the flying capacitor is equal for given switching cycle ($<V_{cf}> = <V_o>$). Hence, for higher values of flying capacitance, $v_{cf}$is approximately equal to the output voltage V_0 thus the current in flying capacitor I_{cf} increases linearly with a slope $Vo/(n^2L_m)$ thus, expression for switch current. For CCM operation, switch S_m is turned-on before the diode current reaches zero. Thus, the currents at the end of this interval are equal to currents at the start of next interval. From the above analysis, it should be realized that CCM operation of ZETA Micro inverter results into lower RMS to average current ratio compared to DCM mode as the current ripple in the inductors L_M, L_o are reduced. This will in turn translate into improved inverter efficiency as the conduction losses are reduced.

III. DESIGN EXAMPLE FOR CCM ZETA MICROINVERTER

This Section presents the major design guidelines for ZETA Micro inverter operating in CCM. The specifications are:

- Input voltage V_{in} = 30 – 40 V DC,
- V_o = 230 V, 50 Hz AC
- Rated power = 60 W.

Average Input Current

The average input current of the inverter can be derived from the efficiency (η) of the inverter as

$$= \frac{}{}$$

Switch Selection

The primary switch selection S_m is important because it operates at High Frequency and carries the highest current in the circuit. Maximum voltage that appears across devices is

$$= \ _{-} + \frac{-}{}$$

$$_1 = \ _2 = \ _3 = \ _4 = \ - \ + \ _{-}$$

Where, V_{in_max} and V_{o_peak} are the maximum input voltage of PV panel, which is 40 V respectively.

Open Loop Modulator

The proposed inverter is buck boost derived (i.e.,) the output of the flyback transformer is stepped down and boosted for the desired output. The gain varies non-linearly with duty cycle, so a non-sinusoidal modulating signal should be used which can be derived as

$$= \quad = \frac{(\quad)}{+ \qquad (\quad)}$$

Transformer Turns

To select the transformer turns, it is required to know the DC gain of the inverter. In an ideal case when operating in CCM a voltage of V_{in} appears across the transformer, when the switch is turned-on and the voltage of V_o appears when the switch is tuned-off.

$$(\quad) - -(1 - \quad) \quad = 0$$

Duty cycle of the inverter is varied such that the output voltage waveform is a rectified sine wave i.e.

$$\frac{}{} = \frac{}{1-}$$

Thus, the transformer turns ratio should be selected such that least possible input voltage should be translated up to peak output voltage using

$$_0 = \qquad (\quad)$$

For this design V_{in_min}, D_{max} are taken as 30 V and 0.65 respectively.

$$= \frac{(1- \quad)}{-}$$

The transformer required for ZETA Micro inverter is the same as that of conventional fly back transformer, which stores energy when the main switch S_m is turned-on and releases energy, when S_m is turned-off. By using an air-gap core, the energy storage capacity of the transformer is increased. In case of Micro inverter, sufficient air-gap has to be given to allow the energy storage without saturation at peak input voltage and for peak power transfer.

Input Capacitor

While the power output of the Micro inverter is time varying, the input power from PV panel must be maintained constant at average value to increase the energy harvest. Thus a large capacitor needs to be connected across PV panel to balance this difference. Voltage ripple due to insufficient capacitance has a significant impact on the MPPT performance and to maintain MPPT efficiency at 99% the maximum voltage ripple allowed is limited to 5%.

$$= \frac{}{2}$$

Where, f = frequency.

At V_{in}= 40 V, 60 W, allowing 5% input voltage ripple requires input capacitor of 15 mF. This is a large electrolytic capacitor, and usually expected to have short lifespan.

L_m and Switching Frequency fs

The values of L_m and f_s are selected such that, the inverter operates in CCM throughout the power range. Generally, at higher switching frequency the value of magnetizing inductance required to keep the inverter in CCM will reduce. It will increase the switching losses and transformer core losses. The relationship between L_m,$f_s$is given as

$$= \quad (\quad = \quad _1) -$$

Selecting $\Delta I_{LM} < I_{in}$, proposed Microinverter can be operated in CCM. At full load with 92% efficiency, $I_{in}$is calculated as 1.5A. To ensure CCM at rated power with L_m= 3.72 mH, switching frequency f_s should be greater than 8 kHz. In this design example, switching frequency is taken as 10 kHz.

Flying Capacitor C_f

Flying capacitor $C_f$is computed to limit the voltage ripple (ΔV_{cf}) in the capacitor to a minimum value, taking ΔV_{cf} = 5% xV_{o_peak}, and the value of capacitance is computed as

$$= \overline{\qquad}$$

AC Filter Design

The output inductor L_o value can be determined based on maximum allowable current ripple in the inverter using

$$_0 = \overline{\qquad}$$

Where $\Delta I = I_{Lo\_peak}$-$I_{Lo}(t_{c0})$. The filter capacitor C_o can be obtained from the ac filter cut off frequency f_c that is usually taken as one tenth of the switching frequency f_s (f_c = 10%x f_s)

Active-Clamp

When the main switch $S_m$is turned-off, a voltage spike appears across it due to the energy stored in the leakage inductance of transformer. This will necessitate use of overrated switches and will reduce the inverter efficiency. Instead, an active-clamp with a small auxiliary switch (S_{ac}) and a series capacitor as shown in Figure 2 can be added. The active-clamp eliminates turn-off spike and recycle the parasitic energy back to the inverter.

$$= \frac{1}{2\sqrt{\quad}}$$

This improves the inverter efficiency by limiting the device voltage.

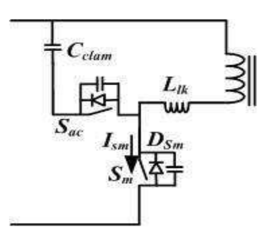

Figure 2: Active Clamp for Main Switch S_m.

III. SIMULATION RESULT

In Figure 3a, Figure 3b shows the input and output, current and voltage of ZETA inverter. From the results, it is

clear that ZETA inverter provides a proper tracking for the PV panels with reduced oscillations.

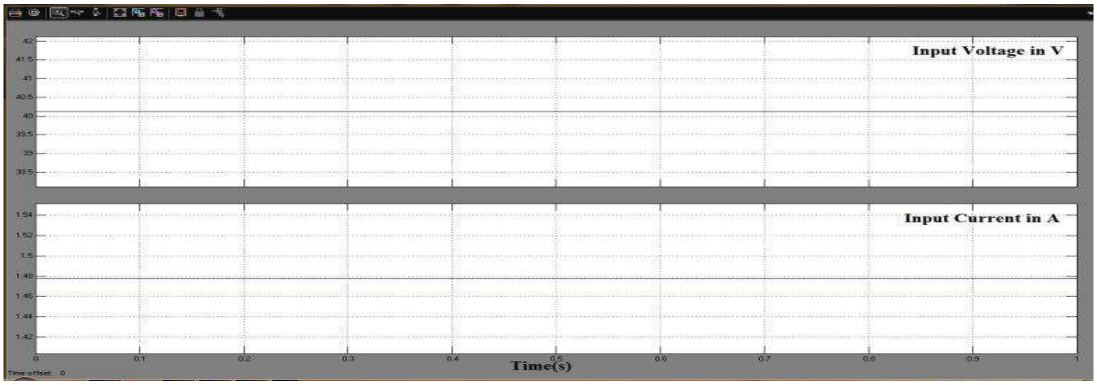

Figure 3.a: Input Response of ZETA Inverter

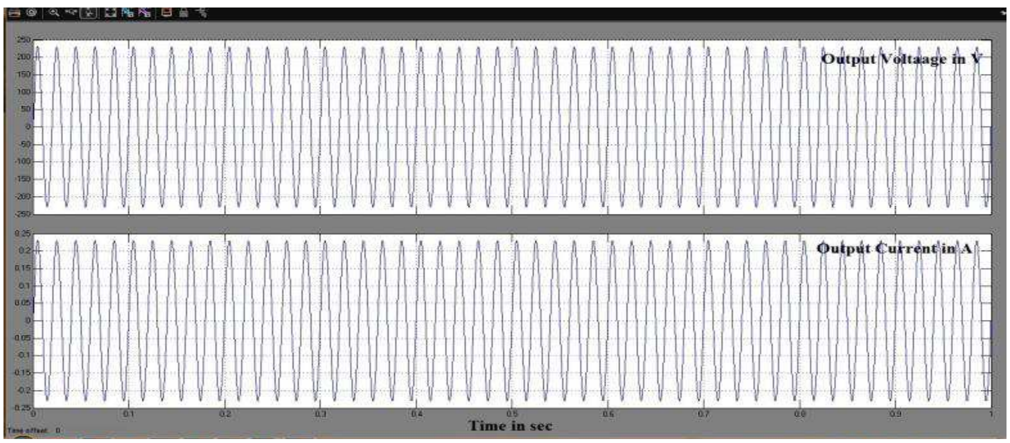

Figure 3.b: Output Response of ZETA Inverter

IV. CONCLUSIONS

Design and implementation of ZETA Micro inverter has been proposed for solar Photo Voltaic AC module. Steady-state operation and analysis of proposed ZETA Micro inverter in CCM has been studied. Micro inverter operation in CCM mode results in

- Reduced conduction losses,
- Switch ratings and
- Current stress.

Traditional Continuous Conduction Mode, fly back inverters have closed loop complexity and stability issues. The proposed inverter provides High Frequency isolation and has only a single switch operating at High Frequency, which will reduce the switching losses. The circuit is simple and easy to develop. A 60 W inverter has been developed and simulation tests are done. The simulation results have a peak efficiency of 95% at rated power of 60 W.

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